

Testimony of Edward J. Woodhouse
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“From Brown Chemistry to Green Chemistry: Barriers and Prospects”
Testimony before the U.S. House of Representatives
Committee on Science
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[Chairman Boehlert](#), [Ranking Member Gordon](#), and Members of the Committee, I [thank](#) you [for](#) inviting me [to testify](#).

I am a political scientist interested in understanding how to shape technological decision making more wisely. I have been studying the social aspects of green chemistry and green chemical engineering since 1998, funded in part by the National Science Foundation. My PhD student, Jeff Howard, with funding from an EPA STAR fellowship, has been doing detailed interviews with green chemists, and I draw selected data and insights from his study.

My purpose here today is to discuss barriers and prospects for moving from [what](#) might be called “brown chemistry” toward a greener chemistry featuring chemicals designed to be benign or close to it. I will begin with general considerations I think members of Congress should be taking into account, then present three simple categories of green chemistry and the legislative opportunities in each, and conclude with some suggestions for further study.

General Considerations

I start with a prediction: The 21st century will see the beginnings of a transnational phaseout of chlorinated and other toxic synthetic chemicals. Economic considerations facing industry, slow-to-change university curricula in chemistry and chemical engineering, and citizens’ ignorance about the potential for benign chemistry may delay the projected phaseout well beyond the time period technically required. Evidence against toxic chemicals is accumulating relentlessly, however, and green chemistry and engineering potentials are developing, even if

more gradually than one would wish. So the main question, it seems to me, is whether public policy will lead or lag.

I congratulate the Committee for its farsightedness in generating the proposed Green Chemistry Research and Development Program, and I regret to report that I find outside this room a certain timidity and lack of vision with respect to the subject. I am sorry to say that most professors of chemistry and chemical engineering appear to be either [uninformed](#) or uninterested, and a few are outright opponents who believe that toxicity is the price for what they would call “progress.” Professional associations such as the American Chemical Society and the American Institute of Chemical Engineers are rhetorically supportive of chemical greening, and even have a few modest programs; but they are not doing much at present to actually inflect the trajectories of their mainstream members. Even environmental organizations such as Sierra Club could be doing a lot more: The National Toxics Campaign and other groups have been pushing for “clean production” and Zero Discharge, which bear on Green Chemistry but do not put it front and center -- perhaps partly because their members resonate with whales, orangutans, and other charismatic megafauna more than with molecules.

Chemical technologies are highly malleable, however, and once it becomes widely understood that what we have been calling “chemistry” actually is a small and relatively backward subset of the chemical universe, the status quo will be on the defensive. The goal of a commendable chemical industry will be nothing less than to make everything using benign materials, and where toxicity cannot be avoided to draw on the services of medicinal and ecological chemists to design chemicals that rapidly decompose and are quickly excreted from living organisms. How closely that goal can be approximated, no one presently knows; what we can say for sure is that many technical achievements that seemed impossible have turned out not to be, in chemistry and

in many other fields of science and engineering. With biocatalysis, nanochemistry, and other techniques not yet dreamed of but surely on the way, those who defend the 20th century's "brown chemical" way of doing things are pretty surely on the road to being discredited. Unless Congress intervenes, however, the transition could take many generations, with untold additional damage to living things around the world.

Everyone acknowledges that contemporary technologies for producing, using, and disposing of chemicals create numerous hazards, some of which result in damages that have to be mitigated or compensated at high cost. There is a sense in which present practices of the chemical industry resemble the "unfunded mandate" that the federal government sometimes is accused of leveling on states: Business-as-usual concerning chemicals makes little provision for medical payments to those affected (except for chemical workers), and little provision for environmental and other damages (except via insurance). As is true of health problems caused by tobacco, many such secondary and tertiary costs of chemical usage are picked up not by the industry itself, but by state and federal medical programs, by medical insurance companies, and ultimately by taxpayers and those who are privately insured. It may be misleading, therefore, to think of new regulations on the chemical industry as creating new costs; rather, costs would be shifted onto producers and users of chemicals – what economists refer to as "internalizing" such expenses by having them better reflected in prices. Tighter regulations would reduce or eliminate the present unfunded mandate that the chemical industry places on other businesses, government, and individual citizens.

It also is worth considering whether there is a commercial risk of waiting to act that may be greater for the chemical industry overall than any one element of it will have an interest in perceiving and acting upon. In particular, the Swedish Chemical Inspectorate already has a list of

250 suspect chemicals that probably are on their way out. The German chemical industry long has paid greater attention to labor, community, and other social interests than do most U.S. firms. Some Chinese technological universities are making a greater commitment to green chemistry than has any U.S. university to date. Altogether, those who care about the competitiveness of the U.S. chemical industry might do well to take heed: If U.S. firms lag behind in moving toward green chemistry, given the long period for amortization of chemical plant and equipment, they may lose market share and endanger profitability during the catch-up phase.

Another general consideration bearing on the legislation can be put in the form of a question: Why is there no explicit research on ethical, legal, and social implications (ELSI) of the \$500 billion-dollar chemical industry and its associated research infrastructure in universities and elsewhere? There have been set-asides or other ELSI initiatives in connection with nanotechnology, climate change research, and other recent technological inquiries. But not for chemistry, chemical engineering, and the chemical industry. Perhaps it could be said that there is plenty of environmental research already underway, even if not directly connected with chemicals? Just so. However, “chemophobia,” as some industry insiders and chemists refer to the public’s distrust for chemicals, grew to significant proportions in the late 20th century partly because most people feel excluded from chemical deliberations and choices. This may be a questionable perception, in that consumers do participate in choosing final products. We feel excluded, and we do not trust, and we do not understand -- and somewhere in that triumvirate is a nontrivial problem concerning the relations of citizens with the chemical industry and the chemical science community. The green chemistry deliberations bring up the possibility of tackling the relationship between chemistry and society in a creative way by focusing on the social components explicitly.

Finally, as Committee members are aware, the amount of funding being proposed in the pending legislation is small compared with the magnitude of the problem – and the magnitude of the opportunity. Of course, there already are funds being expended, as the other witnesses have pointed out; and, of course incremental funds are a fine idea. So I do not really quarrel with the idea of adding to Green Chemistry R&D within the limits of what will be considered fiscally prudent. Still, looking toward the longer term, it is worth noting that although no one knows the exact number, there are some ten thousand toxic chemicals that may need to be replaced.

Taxpayers this year are spending approximately one hundred times as much on nanoscience and nanotechnology research than will be spent under the new Green Chemistry legislation, despite the fact that, in my opinion, Green Chemistry is a more important problem and a more important opportunity. Some observers would go so far as to characterize the nanotechnology juggernaut as a set of techniques in search of a serious issue worthy of taxpayers' concern. I would not go that far. In the case of brown chemistry, however, we have a known problem of proportions far larger than the expenditures now being contemplated.

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I turn now to some more specific ideas concerning barriers to the greening of chemicals, and prospects for circumventing or lowering some of those barriers.

Three Categories of Green Chemistry

Chemists divide their world into many technically interesting and important categories, such as solid state, lipid, and carbohydrate chemistry; for our purposes, however, there are just three main commonsensical categories of interest:

1. Green chemical techniques and products that industry may voluntarily utilize because there are no added costs, and sometimes even cost savings;

2. Well understood chemical processes and products that industry probably will not voluntarily utilize, because they are more expensive than current practices; and
3. Potential green chemistry techniques and products that are not yet known or understood.

The goals of public policy should be:

- 1a. To craft chemical education to make sure that chemists and chemical engineers have the knowledge and skills to make good use of available GC techniques that are already affordable in category one;
- 2a. To encourage industry to utilize some of the “too-expensive” GC in category two -- where a changeover would help solve significant problems created by present chemical technologies; and
- 3a. To invest in R&D within category three, in order to expand the repertoire of green chemical techniques and products.

Green Chemistry Education Policy

One of the most disturbing things I’ve observed in my research is how slowly the educational institutions are changing over to Green Chemistry. Not atypical is the situation at one technological university not far from here, where the GC curriculum consists of a single, one-credit course, team taught as a free-standing elective without any connection to the mainstream curriculum. When I asked a chemistry chairperson at a different university about some elementary steps his department could take, he replied, “We do not have room in the curriculum.” At another university, the chairperson tried to lead but his faculty refused to follow, saying “That’s not the way it’s done at Harvard or Chicago.” One indicator of the situation, as pointed out by a leader of the Green Chemistry movement, Chemistry Professor John Warner of the University of Massachusetts: About half of U.S. chemistry departments still require PhD students to pass a qualifying exam in a foreign language, but not one requires equivalent proficiency in toxicology.

Now, I acknowledge that meddling in university curricula is a dicey proposition; not trying to improve the situation seems irresponsible, however. What might legitimately be done? One thing we know is that hardly any university departments turn down funding. I expect that members of this Committee would be taken very seriously were some of you to approach the Ford Foundation or other major independent funding sources regarding a Green Chemistry education initiative, perhaps jointly with the National Science Foundation, the American Chemical Council, and other sources? Adding courses in ethics to chemistry and chemical engineering curricula might be the direction to head: One of the leading Green Chemists, Professor Terry Collins at Carnegie Mellon, has added a significant ethics component to the curriculum there, and advocates that it be added elsewhere.

A parallel tack: Most universities depend on periodic renewals of their accreditation to certify to parents and others that the organization is recognized as offering an appropriate educational environment. At present, the accrediting organizations such as Middle States are not paying attention to whether universities continue to train chemists and chemical engineers in the older approaches or are training students in benign-by-design chemistry. The accrediting agencies should be paying attention, of course, and although I have not studied the matter I am confident that there is a way to encourage them to do so.

A third glaring weakness in the training of chemists is that they do not have to pass through professional licensing, and even chemical engineers can be exempt from it if they work in industry. Those who do sign up for the professional licensing exam administered by the American Institute of Chemical Engineers. I was unable to secure cooperation of the AIChE in my attempts to study the test or the processes behind it, so my information is less complete than I would like. But study guides for the test have changed very little in the past decade, continue to

give far more attention to economics than to environmental issues, and evince zero appreciation of the spirit or letter of green chemistry. This appears to be true partly because the AIChE licensing process relies on retired engineers who volunteer their time, rather than on forefront chemical engineering researchers. The Science Committee obviously does not control professional licensing, but chemistry-in-application involves not high-profile researchers but rather ordinary chemical engineers. If they are to function, in effect, as society's delegates in the chemical plants, we need some way to persuade and incentivize them toward greener chemicals.

In short, there are some social barriers to better GC education that are not immediately apparent, and that may not yield readily to research grants or even graduate fellowships. It would be worth a patient inquiry into the matter by those with relevant expertise and access, perhaps as part of the report requested by the pending legislation.

Category 2: GC Affordability and Uptake for Industry

Some of the most knowledgeable advocates for GC speak as if the transition process might be pretty much automatic: Develop the knowledge, and industry will utilize it. I am a bit skeptical of that, as I expect you are. There already is a repertoire of GC knowledge that is ready, but is not being used; and knowledge of that sort is certain to increase as chemical researchers push beyond present understandings of the GC universe.

One example is a water-soluble, biodegradable polymer that the Rohm & Haas Chemical Company developed for use as a brightening agent in laundry detergent. Despite seven years of effort and proven results, the industry continues to use the old non-biodegradable brightener, because the new one would cost about twice as much per ton. When I asked how that would translate at the consumer level, the chemical executive replied, "About one penny" – raising the

price of a bottle of detergent from \$4.00 to \$4.01. For Procter and Gamble, however, that might amount to a million dollars a year if they have to absorb the price increase (which they would not, if every company were required to use the new method).

Technology-forcing statutes of the sort used to reduce air pollution probably are the way to tackle issues of this sort, along with tradeable pollution permits, scalable excise taxes, and tax credits; but I realize that such matters are outside the jurisdiction of the Committee on Science. I just want to let you know some of the economic and other barriers I perceive to chemical greening, so that, over time, you can do whatever seems feasible within your domain.

For example, recognizing the barriers to industry participation, the Committee already has taken the laudable step of including chemical engineering research in the pending bill. Still, given the relatively higher status of chemistry, it seems to me likely that chemists will garner the lion's share of the funding. That's fine, if long-term, basic research is really what we want to stimulate. I wonder, though, if more nearer-term engineering efforts might be designed to help move category two knowledge into category one, so that the odds of it being adopted by industry would go way up. This would involve reworking known chemical processes to be greener with the lowest possible incremental costs. Because down time is such a no-no in the industry, for example, any ways of minimizing it translate pretty directly to the bottom line. Engineering researchers may be able to figure out how to minimize disruption of existing chemical production plants, equipment, and processes. Some of the EPA and NSF programs already are doing this, I acknowledge, but they are mainly directed at solvent replacement rather than more complex matters.

I know that many people are reluctant to "pay industry" for doing things "it should do on its own," however I would urge that in setting up the GC research efforts under this bill that your

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Committee establish relatively permissive guidelines. Some of the people who are best positioned to move GC knowledge from category two into category one are those with closest ties to the industry. If they chose to participate in R&D under this bill, I for one would be thrilled rather than dismayed. The draft of the bill I initially read seemed to be heading more in the direction I would favor than the latest draft, which has removed the term “commercial application” in quite a few places. I realize that the matter is a thorny one involving jurisdictional issues, and that the boundary between industry-funded and government-funded endeavors has implications for many aspects of the federal budget. Nevertheless, I recommend that you consider tilting toward greater support for industrial R&D than might normally be appropriate for federal funding of applied research.

The education (or mis-education) of chemists and chemical engineers plays a role in this category also: Not many of our recent graduates are prepared to figure out technically and economically feasible alternatives to the chemical status quo. Just as importantly, they are not operating within a Green Chemistry mindset, and hence are not likely probe very intensively to create new ways of working with chemicals. Note that this way of thinking about chemical greening means that accountants, managers, and attorneys also get drawn into analysis of corporate choices regarding chemical products and processes – implying that, at least in principle, one should be thinking about the education and ongoing training of persons holding such roles. It makes sense initially to suppose that it all comes down to formulas and other relatively straightforward analysis; in fact, it is the culture and psychology of the relevant disciplines and businesses that is as much at issue. None of us well understands how to go about intervening in such complex social phenomena, of course, so my point is merely that we need to be acting so as to turn out much larger numbers of greener chemists, chemical engineers, and

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others as a way of seeding the industry. In the interim, a great many opportunities for changing chemical pathways, processes, and products may be missed by those operating under the old governing mentality green chemicals are technically impossible or unacceptably expensive.

Category Three: Funding Forefront Green Chemistry Research

I actually have the least to say about this category, even though it probably is the one that comes to mind most readily when one thinks about stimulating R&D in an emerging field. Certainly it is easy to catalyze more Green Chemistry; if you provide the funds, researchers will indeed create justifications for obtaining the money.

Green chemistry is a bit like the Nixon “War on Cancer” or the current holy grail, nanotechnology: Many existing chemistry projects can be tweaked so as to qualify for the new funding. That’s not bad, in a way; however, if what one really wants is to catalyze breakthroughs, I’m not sure we know right now how to design a program to achieve that. There’s usually something to be said for learning by doing, and one can interpret in that way the three years of funding that would be authorized via the proposed legislation. I do not object to that exactly, but I have seen NSF disburse sums greater than I considered warranted – as in the current round of funding for nanotechnology education proposals I just reviewed last month. Hence, I wonder if there might be a way to at least get a prioritized research agenda at the end of the three years as part of the report to Congress required by the proposed bill.

Further Study of Social Barriers and Prospects

The general provisions for further study in the proposed bill make good sense to me.

However, either as part of the bill itself or during its implementation, I would like to see some fine-tuning along the following lines.

First, as suggested earlier in the discussion of ethical/legal/social implications, social science and policy are not ruled out by your proposed wording, but neither are they made as central as the situation may justify. Of course there are important scientific and engineering issues that need to be studied; but much of what stands in the way of chemical greening is social and economic in nature.

That said, I am no fan of the ELSI set aside as part of climate change research, because too much of the money went for relatively trivial investigations. I have to admit, however, that a three-percent or five-percent set aside does draw the attention of social scientists, historians, and environmental philosophers, and we need some way of getting more of them to attend to the brown/green chemistry problem/potential. It is odd to have a problem and opportunity of the magnitude of Green Chemistry with so little systematic social analysis available, and I would like to see this Committee catalyze enough study that when you reconvene for a renewal hearing on this legislation, a lot more social scientists knows something about the subject.

Second, the state of policy thinking on the subject is rudimentary. To my knowledge, there literally is no one who has systematically studied the matter, and no organization equivalent to the former Office of Technology Assessment has drawn in the relevant stakeholders for sustained discussions. Foundations are not funding or studying the problem in the way that the Heritage Foundation, Brookings, and American Enterprise study so many important matters of public policy. Environmental economists are applying their increasingly refined skills to many environmental issues, but not to brown/green chemistry.

Third, and closely related, the problem of brown chemistry is only about ten percent a matter of shortages in supply of technical knowledge – and about 90 percent lack of demand for an alternative to brown chemistry. This Committee’s jurisdiction obviously pertains to the improvement of science and technical knowledge, not to regulation of the chemical industry. However, this Committee may have an indispensable role to play in catalyzing interest by other relevant committees, ones with more [regulatory](#) authority ~~over~~ the subject of chemicals. It is of course a dicey matter of how to handle such intra-congressional matters, and I have no wisdom to offer superior to the tacit knowledge you have acquired.

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I would urge you not to underestimate the bully pulpit role, however. We associate it with the presidency, especially as popularized by the first Roosevelt; yet most governance is partly a matter of persuasion, and persuasion is largely about good reasons when monetary or other inducement has little bearing, as in intra-congressional life. How might this Committee use its staff, use its connections in the relevant industries, use its members’ connections with other committees, and use whatever one-on-one connections there may be with other relevant legislators, industry executives, and executive branch personnel? Such matters rarely are brought up directly in hearings, of course, and yet they occur daily in governmental life. I wonder if there isn’t a way to make enrollment of other committees in an overall push for greener chemistry a higher priority?

One example of the kind of policy proposal that would galvanize industry demand for Green Chemistry would be a revenue-neutral tax and subsidy program. Place an excise tax on sales of some of the most suspect categories of existing chemicals, perhaps scaled by industry itself based on estimated risks, and give the funds back to chemical companies as tax credits for innovations in benign chemicals. In effect, the innovative companies would be paid by the

laggards. Inasmuch as the largest companies in the industry tend to have the best R&D staffs, and hence are most capable of using technological leadership for competitive advantage, a side effect of the policy probably would be to accentuate the comparative advantage of the most dynamic companies. Among other results, this might better position them for international competition if a transnational phase out of chlorinated hydrocarbons should eventuate.

Finally, it seems to me that the Green Chemistry case raises questions about how public-interest science gets done in the U.S. We proceed as if it were a nonpartisan search for truth, when we all know that ideology, careerism, narrow-mindedness, and habitual thinking are common in science as in other human endeavors. As Michael Crichton expressed the point,

Just as we have established a tradition of double-blinded research to determine drug efficacy, we must institute double-blinded research in other policy areas as well. Certainly the increased use of computer models, such as GCMs (global climate models), cries out for the separation of those who make the models from those who verify them. The fact is that the present structure of science is entrepreneurial, with individual investigative teams vying for funding from organizations that all too often have a clear stake in the outcome of the research -- or appear to, which may be just as bad. This is not healthy for science.

Sooner or later, we must form an independent research institute...funded by industry, by government, and by private philanthropy, both individuals and trusts. The money must be pooled, so that investigators do not know who is paying them. The institute must fund more than one team to do research in a particular area, and the verification of results will be a foregone requirement: teams will know their results will be checked by other groups. In many cases, those who decide how to gather the data will not gather it, and those who gather the data will not analyze it. (Crichton 2003).

I find his expression of the idea a bit formulaic, but the core insight has merit. We are in the state we are, trapped in Brown Chemistry, partly because chemists and chemical engineers worked first of all for industry, secondly for themselves and their organizations, and only thirdly for the public. They operated as insiders, not with bad intent but with bad effect, and the

arrangement made perfect sense, in a way, considering who was paying. There is a sense in which 20th-century chemistry and chemical engineering did not go through sufficiently rigorous “social purposes review” with respect to basic considerations about brown versus green design of chemicals. If Congress and the citizenry want a different sort of chemistry, and a different sort of public-regarding science more generally, it might make sense to face up squarely to the fact that genuine accountability may require more sophisticated arrangements than we now have.

Conclusion

In recent interviews, Jeff Howard asked a half dozen of the world’s leading Green Chemists about impediments to chemical greening. By a wide margin, they said that “economic inertia” was the most significant barrier and “professional inertia” came second. Scientific uncertainty and other technical matters were rated as important but lesser barriers. In other words, social factors are more important barriers than purely technical ones.

Although I strongly support the legislation pending before this Committee, therefore, I recommend thinking of it as one step in a long process. For the future, I recommend that the Committee consider ways to:

- Increase funding (including tax credits) well beyond what is presently feasible;
- Look into some of the mundane aspects of Chemistry and Chemical Engineering education, in order to catalyze curricular change, promote chemical ethics education, revise university accreditation procedures to enhance social responsibility, and improve professional licensing.
- Draw social scientists and ethicists into study of Brown/Green Chemistry;
- Stimulate chemical engineering economics research to prepare the way for industry adoption of Green Chemistry techniques;
- Go outside the established funding agencies and advisory mechanisms for policy analysis bolder than what can make it through the [traditional](#) procedures;

- Use the Brown/Green Chemistry case to reconsider how to arrange much more sophisticated public-interest science;
- Envision a long-term process via which this Committee plays a leading role in helping humanity re-vision its relations with chemicals.